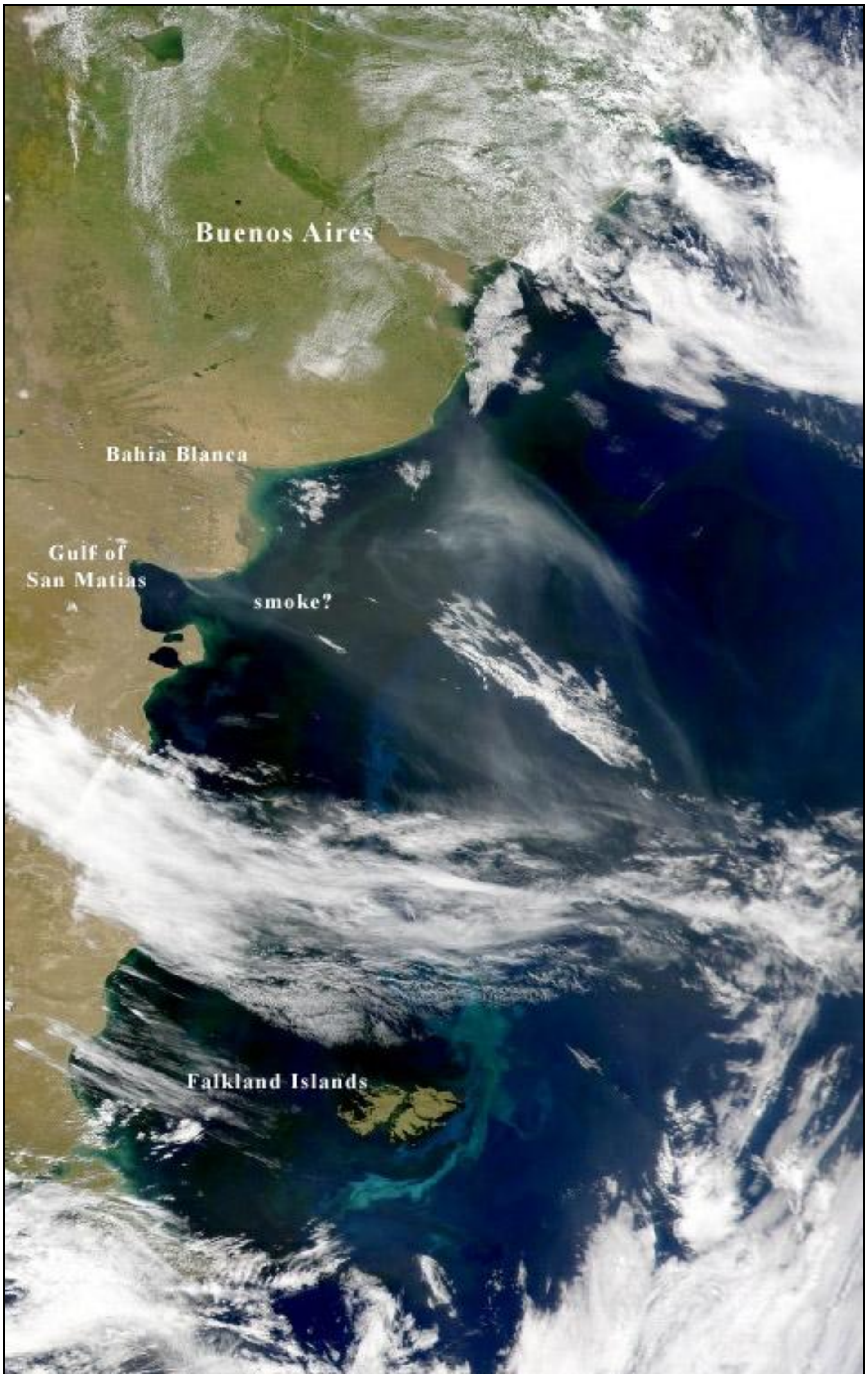
SCIENCE FOCUS: Data Processing

More than Meets the Eye



The image shown on the previous page was created from remote sensing data obtained by SeaWiFS on January 15, 2001. The image covers much of the Argentinian coast, from the muddy-brown estuary of the Rio de la Plata in the north to the Falkland Islands and Patagonia at the southern tip of South America to the south. The city of Buenos Aires is located on the southern coast of the Rio de la Plata estuary. Two other coastal features are labeled on this image: Bahia Blanca, a turbid coastal area, and the clear water, dark blue Gulf of San Matias. These two areas show that diverse ocean optical conditions can be located in close geographical proximity.

The Gulf of San Matias is an important ecological area, due to its protected deep cold waters: it is the main breeding site for the southern right whale, one of the most endangered whales in the world, and supports large populations of seabirds, penguins, sea lions and elephant seals. Much of the land around the gulf is part of the Patagonian coastal steppe, with a unique population of land animals including guanacos (a species of wild llama), Patagonian foxes, maras (the Patagonian hare), puma, burrowing owls, peregrine falcons, flamingos, hairy armadillos, rheas, and burrowing parrots. Because there are no national parks or preserves in this area, it is endangered by sheep farming. However, some conservation groups have recently initiated programs to purchase large tracts of privately-held land for conservation purposes.

This image was selected to illustrate our *Science Focus!* article on SeaWiFS data analysis due to the variety of oceanographic and atmospheric conditions it contains. Near Bahia Blanca, smoke may be carried seaward from grass fires. The sediment-laden waters of the Rio de la Plata challenge the most sophisticated analytical algorithms.

One of the most prominent features in this image is the bright blue-green phytoplankton bloom that winds from the southeast to the northeast of the Falkland Islands. Due to the color of this bloom, and the cold water environment, this feature appears to be a coccolithophore bloom. Coccolithophores, the most common of which is a species named *Emiliania huxleyi*, are phytoplankton that create microscopic plates of calcium carbonate ($CaCO_3$) called *coccoliths*. The coccolithophores cement these plates around them to form a *coccosphere*. The presence of millions of microscopic pure-white coccospheres in the water, as well as free-floating coccoliths, creates a very bright and reflective ocean optical condition. Due to their brightness, coccolithophore blooms can cause ocean optical algorithms, intended to calculate chlorophyll concentration and other parameters, to produce erroneous results.

The SeaWiFS image shown on the first page is an example of a "Level 1A" image. It was created using the radiances from three SeaWiFS bands (approximately red, green, and blue) and combining them to produce nearly natural colors. For this image, some of the effects of light scattering by the atmosphere were corrected, so the colors appear more vivid than if they would be if viewed from space at the orbital altitude of SeaWiFS.

Note in the image that the possible smoke appears gray and somewhat transparent compared to the brighter white of atmospheric clouds. Data processing is capable of removing some haze and smoke. So the first step in further analysis of this data is to process the data from Level 1A – the radiance data obtained by the satellite – to Level 2.

Step II: Level 2 Data Processing

Processing Level 1A SeaWiFS data to Level 2 is accomplished using SeaDAS, the SeaWiFS Data Analysis System. SeaDAS processing, which duplicates the data processing performed by the SeaWiFS Project, does a remarkable number of things when it processes a scene to Level 2. Using input data -- either contained in the SeaWiFS data itself, such as the radiances at 765 and 865 nm, which are used for atmospheric correction, or additional meteorological and atmospheric ozone data -- the influence of the atmosphere is removed for each pixel, and the radiances are converted to "normalized water-leaving radiances" (nLw). nLw means that the radiance values are equivalent to what would be measured right on the ocean surface with the sun directly overhead. When oceanographers on research cruises make ocean optical measurements, they attempt to duplicate these conditions as closely as possible.

Data processing also analyzes the data for a number of different conditions. If any these conditions are detected, the pixel is assigned a "flag" or a "mask". Flags and masks will be discussed in Part IV.

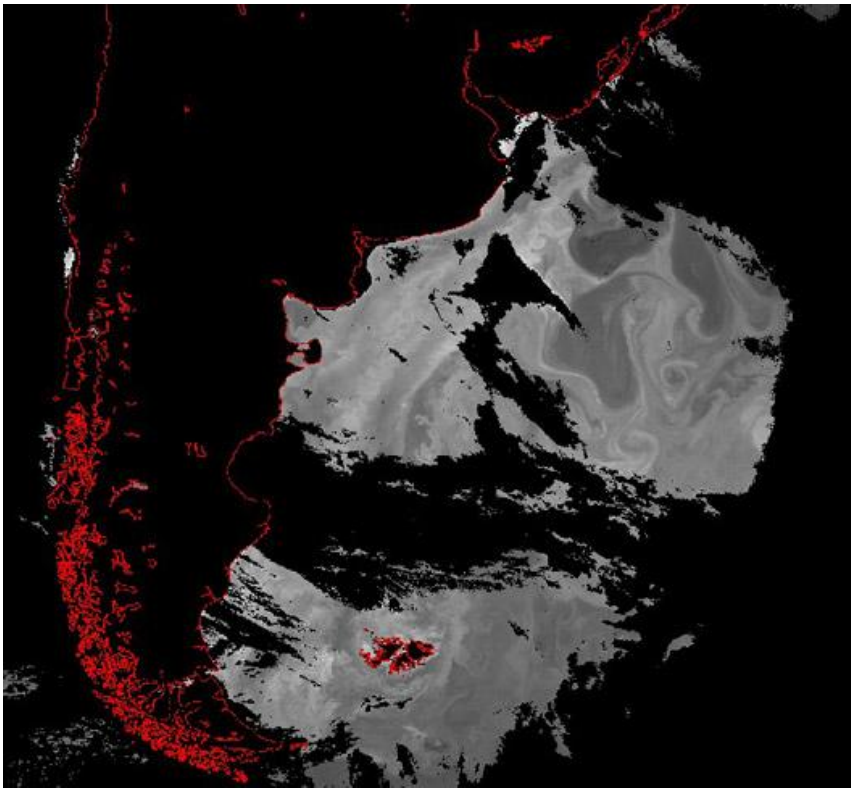
After the nLw values are calculated, other algorithms can be applied to the data. The most popular SeaWiFS algorithm is the chlorophyll algorithm, which calculates the concentration of chlorophyll in milligrams per cubic meter of water (mg m^{-3}). The updated SeaWiFS chlorophyll algorithm is called the "Ocean Chlorophyll 4 (OC4)" algorithm, because it uses four SeaWiFS bands. This algorithm is described in Volume 11 of the SeaWiFS Postlaunch Technical Memorandum Series.

Dr. Jay O'Reilly provided a summary of how the chlorophyll algorithm worked:

"OC4 is a 'maximum band ratio' algorithm where the maximum of three band ratios (443/555, 490/555, and 510/555) is used to predict chlorophyll concentration.

"Over most of the deep ocean, chlorophyll concentrations are below 0.3 mg m^{-3}, and water-leaving radiance in the 443nm band exceeds the radiance in the 490nm and 510nm bands. At chlorophyll concentrations above 0.3 mg m^{-3} and below 1.5 mg m^{-3} (values typically found on continental shelves), water-leaving radiance in the 490nm band is usually greater than the values for the 443 and 510nm bands. Finally, at chlorophyll concentrations above approximately 1.5 (mg m^{-3}), frequently found near shore, water-leaving radiance in the 510nm band exceeds that measured in the 443nm and 490nm bands. In fact, in both chlorophyll-rich waters and phytoplankton blooms, the estimate of water-leaving radiance for the 443nm band (after atmospheric correction) may be noisy and too low to make accurate chlorophyll estimates. The OC4 algorithm takes advantage of the natural shift in the dominant radiance band, and by using the brightest band (443,490,510) in the band ratio, the algorithm is able to estimate chlorophyll concentrations with a high level of accuracy over the wide range that exists in the global ocean."

The results of data processing and the application of the OC4 algorithm are shown on the next page. The image shown is a "grayscale" image, where the chlorophyll concentration values are assigned different levels of gray, ranging from black to white. The coastline for all land masses has been added (in red).

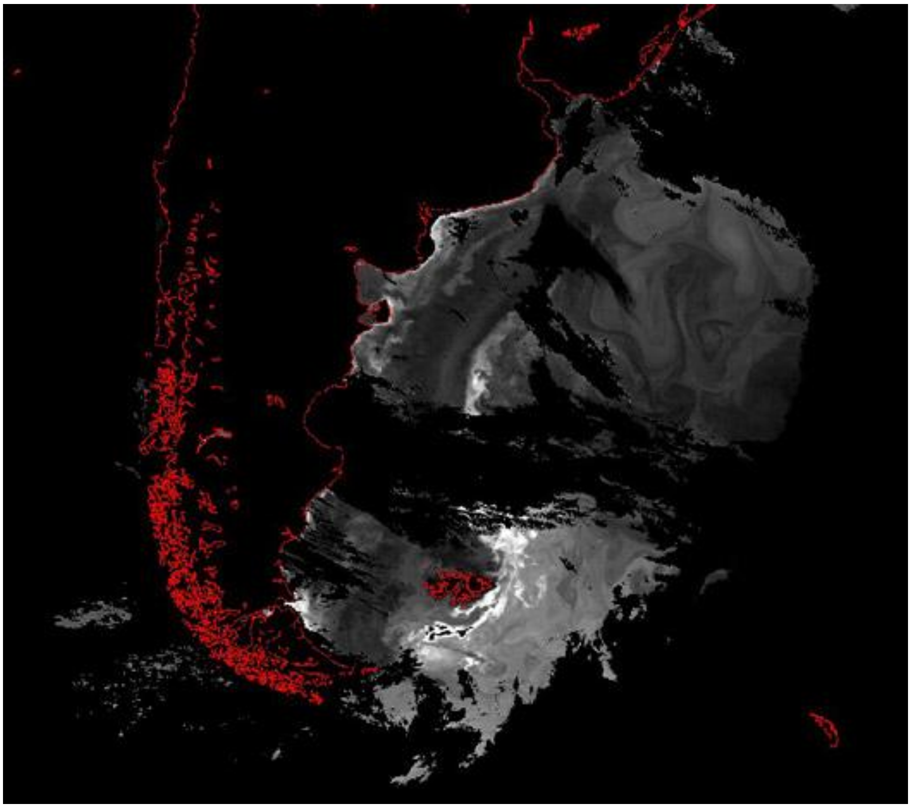


It is now obvious that there is considerably more oceanic activity here than first meets the eye (compare this image to the true-color image on the first page). This oceanic region is a very dynamic region where two strong ocean currents interact (a previous *Science Focus!* article on convergence zones explains what's happening here in more detail). The interaction of these currents gives rise to the complex circulation patterns and variable chlorophyll concentrations that are apparent in this image.

Note that in the region near Bahia Blanca where smoke may be present, data processing has removed some of the interfering haze. However, the thicker areas are interpreted as cloud (shown here as black).

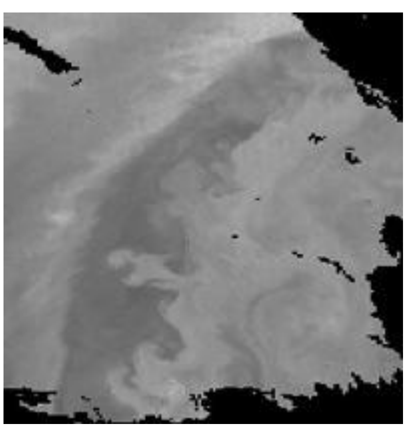
The phytoplankton bloom area near the Falkland Islands doesn't appear very prominent in this image. This is due to the fact that the chlorophyll algorithms are based on the absorption of light by the chlorophyll pigment in phytoplankton cells. Because coccoliths are highly reflective, they reflect much more light than they absorb even though they contain chlorophyll.

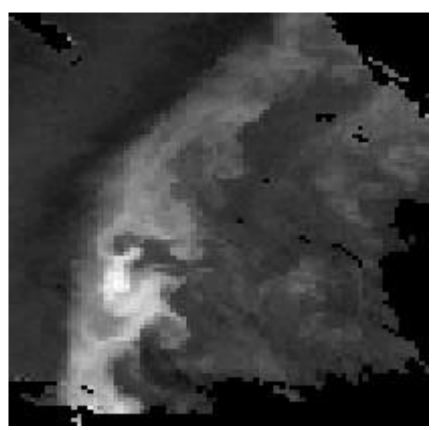
Now compare the chlorophyll concentration image above to the grayscale image shown on the next page. This image displays nLw(490), the normalized water-leaving radiance at 490 nm.



The suspected coccolithophore bloom near the Falklands is much brighter here, because sunlight at a wavelength of 490 nm is reflected strongly.One of the characteristics of coccolithophore blooms is that they are almost pure white: they reflect all wavelengths of visible light very efficiently.The small areas of black that appear on the brightest areas of the bloom are a SeaWiFS data "mask" that will be explained in Part IV.

To demonstrate the difference between nLw and chlorophyll concentration, two close-up views of a feature that looks somewhat like a lobster claw are shown below. This feature appears just above the line of clouds that separates the two clear water areas of the image.



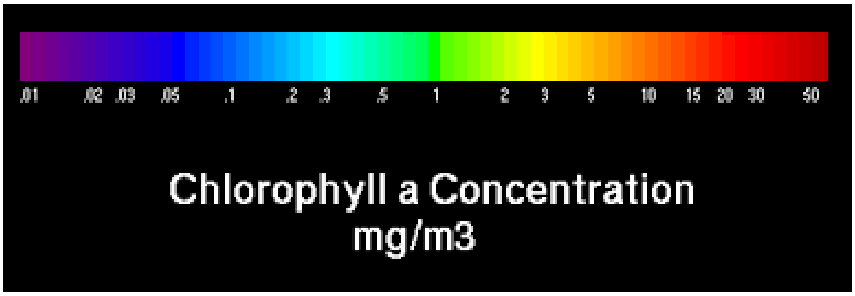


The image on the left is the chlorophyll data, and the image on the right is the nLw(490) radiance data.The lobster claw feature has higher chlorophyll concentrations than the water surrounding it, so it absorbs more light at 490 nm than the waters around it. Thus, it appears as a darker feature in the radiance data.

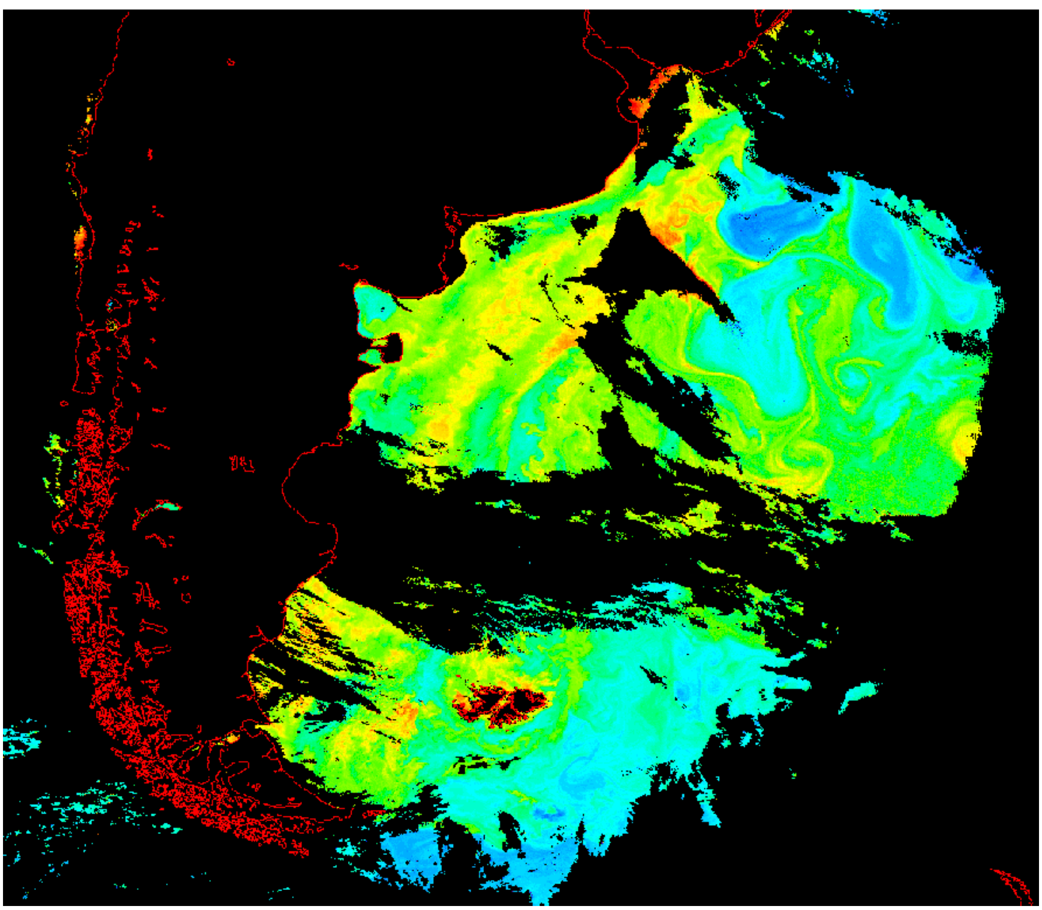
The next step will be to add color to the chlorophyll data, to get a better idea of where the chlorophyll concentrations are high and where they are low.

Step III: Adding the Color Palette

The next step in the analysis is actually quite simple, but it makes the data somewhat easier to examine visually.The SeaWiFS chlorophyll color palette is added to the image.The color palette uses shades of purple and blue for low chlorophyll concentrations, with green, yellow, orange, and ultimately red for higher chlorophyll concentrations:



When the color palette is applied to the image, the result looks like this:



Now the variability of chlorophyll concentration is more easily perceived. However, some of the detail is lost due to the fact that there are more grayscale hues than color gradations in the palette, i.e., the chlorophyll concentrations are "grouped" into various colors. (There are other palettes than this “rainbow” palette that might work better, but the rainbow palette has been used for many years.)

At the mouth of the Rio de la Plata estuary, the orange and red hues of the palette can be seen.Those colors indicate high chlorophyll concentrations, but are questionable due to the presence of high concentrations of sediment. Ocean optical scientists are actively working on algorithms that can produce reliable chlorophyll concentrations in turbid waters such as these.

The next step is to use the flags and masks that have been added to the data to look for some particular conditions.

Step IV: Masks and Flags

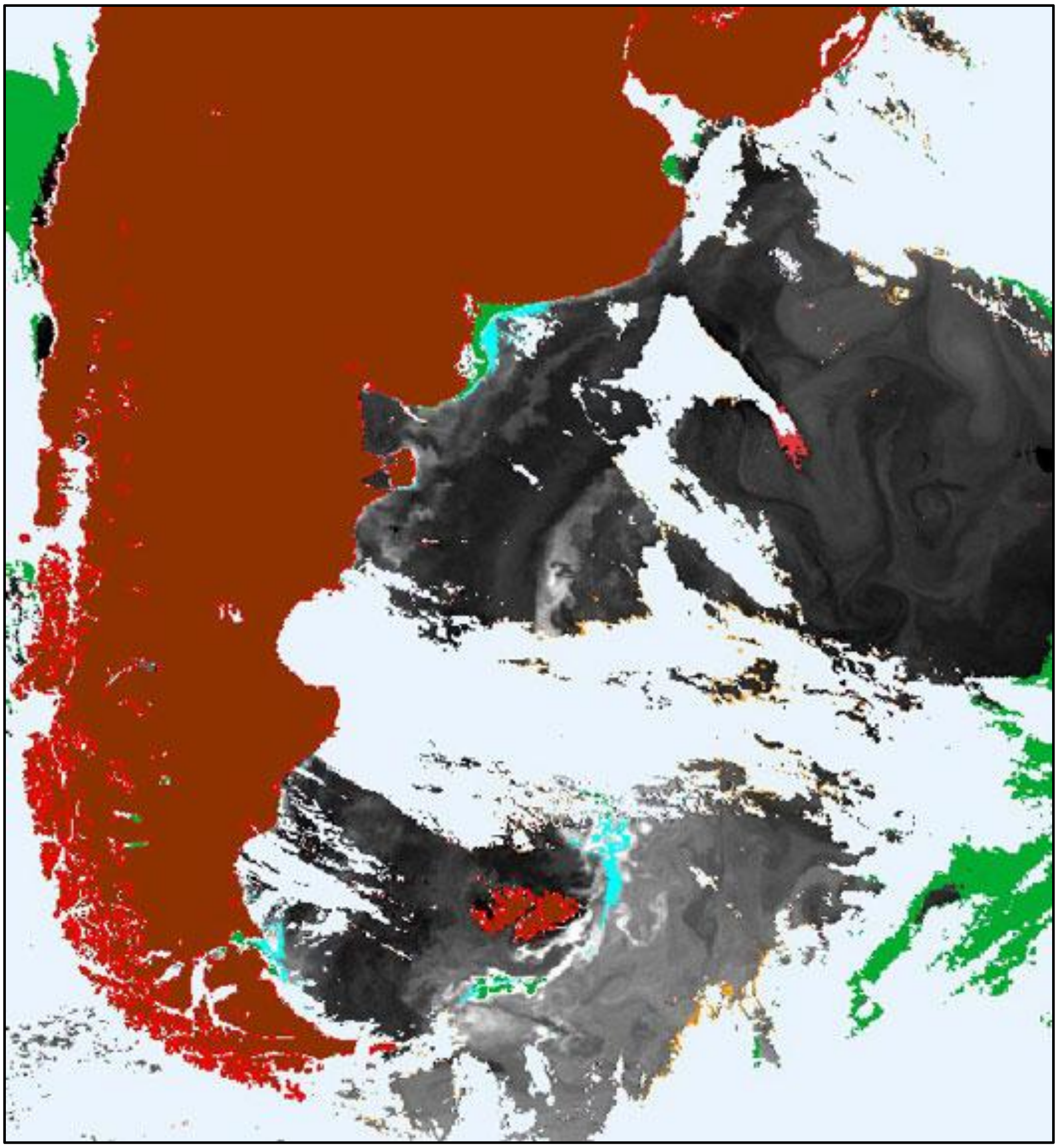
Now that the chlorophyll concentrations have been visually presented, it's time to take a look at some of the various conditions that are present in the data.A "condition" only means that a particular pixel in the data file has certain characteristics (it's not a disease). A simple case is where the pixel is located on land.In that case, the land "mask" is applied.When Level 1A data is processed to Level 2, any pixels covered by the land mask are not processed, which saves time.

Other masked conditions are the presence of clouds (which are detected by a high radiance value) and "radiance above the knee".The latter refers to the way that SeaWiFS is capable of imaging both land and water. Water is much, much darker than land, optically speaking, so SeaWiFS has two gain settings that allow it to discriminate varying radiance levels over water and land.The gain setting for water allows the instrument electronics to process light levels linearly up to a certain threshold (the "knee"), at which point a higher linear gain is used.This feature prevents saturation of the sensor over particularly bright areas, and is referred to as a *bilinear gain*. When an oceanic area is so bright that it exceeds the radiance threshold for the lower gain setting, the "radiance above the knee" mask appears.

SeaWiFS data processing also analyzes the data for several conditions that can make data analysis uncertain. For any pixel with one or more of these conditions, a "flag" specific to that condition is given to that pixel.These conditions include a large angle between the pixel and the satellite (which occurs at the edges of the scanning swath), different types of atmospheric aerosols, failure of the analytical algorithms (i.e., the calculation doesn't return a meaningful value), or the presence of turbid or sediment-laden water. Two types of phytoplankton are also flagged: coccolithophore blooms and *Trichodesmium*, a species that can fix nitrogen from the atmosphere.Any pixel can have several different flags.

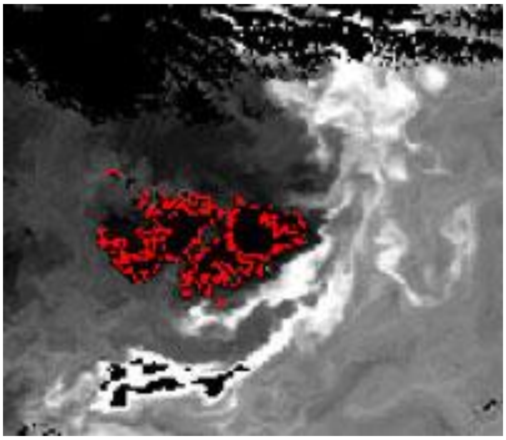
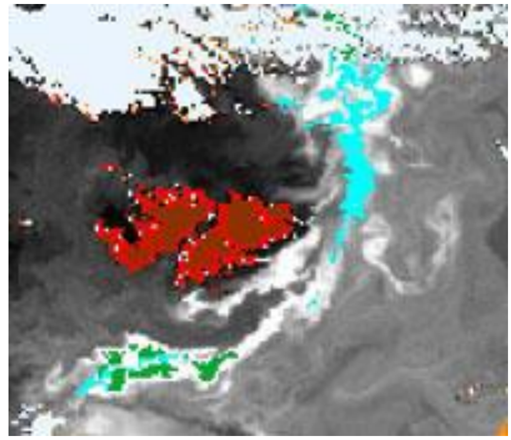
The coccolithophore bloom algorithm was created based on both surface and satellite observations of coccolithophore blooms.It uses nLw values to determine if the characteristic optical signature of a coccolithophore bloom is present. It isn't perfect: areas that are not coccolithophore blooms can be flagged, and areas that very likely are coccolithophore blooms might be missed. Even though that must be kept in mind, the algorithm works quite well. The current coccolithophore bloom algorithm is described in Volume 9 of the SeaWiFS Postlaunch Technical Memorandum Series.

The image displayed on the next page shows the nLw(490) data and features three masks (brown for land, white for clouds, and green for radiance above the knee) and three flags (blue for coccolithophore blooms, yellow-orange for low nLw(555), and red for absorbing aerosols). Look for each of these colors.



Most of the masks are found where they probably should be assigned (which is desirable).The only place that the absorbing aerosol flag appears is attached to the tail of the diamond-shaped cloudy area below the Rio de la Plata estuary.In the true-color image, this area appeared as hazy cloud, and not as bright as other clouds nearby.So it is possible that this is a smoke aerosol. The low nLw(555) flag only appears on the edges of clouds.This condition is likely due to the fact that it takes the sensor and electronics a few milliseconds to adjust when the sensor's scan makes a transition at the edge of a bright cloudto dark water.

Now for a closeup view of the area around the Falkland Islands:

The left image is the 490 nm radiance data without flags, and the right image is the 490 nm data with the flags added.In the left image, the black patches interior to the bright areas were suspected to be the "radiance above the knee" mask;they are green in the flagged image, so this is correct.The blue coccolithophore flag has been assigned to a significant area of the bloom.This flag data helps to verify the suspicion that the bright blue-green waters seen in the true-color image are in fact due to a coccolithophore bloom.

However, also note that in the full-scene image on the previous page, the turbid waters of Bahia Blanca have also been flagged as a coccolithophore bloom, and the "radiance above the knee" mask appears inland of the coccolithophore flag.In this case it helps to view the true-color image and see that this is an area of turbid water, which indicates that this is less likely to be a coccolithophore bloom.